BACK TO MARS: THE MARS PATHFINDER MISSION

Richard A. Cook and Anthony J. Spear
Mars Pathfinder Project
Jet Propulsion Laboratory

Abstract

Mars Pathfinder successfully landed on the surface of Mars on July 4, 1997, and ushered in a new era in Mars exploration. This era will feature numerous low cost missions which will perform important science investigations and engage the world's population in the excitement of planetary exploration. Pathfinder has obtained already obtained a set of significant science results relating to Martian geology and geomorphology, mineralogy and geochemistry, magnetic and surface properties, atmospheric properties, and orbital dynamics. In addition, the Sojourner microrover has traversed the area surrounding the lander and has performed several key technology experiments. The Pathfinder mission has also proven to be one of NASA most popular efforts with the general public. The Mars landing event marked a turning point in the use of the Internet when more than 400 million "hits" were received in the first two weeks after landing. The unprecedented level of excitement and interest should

Introduction

Mars Pathfinder was one of the first missions in NASA's "Discovery series of low cost planetary missions. The project was started in October 1993 with the goal of placing a lander and rover on the surface of Mars for less than $150M (FY'92 dollars). In order to achieve this goal, the project had to invent a new way of doing business within JPL and NASA. Key elements of this "Faster, Better, Cheaper" implementation approach include physical co-location, concurrent engineering, balanced risk management, and reliance on a strong end-to-end test program. This new approach is one of the key legacies of the Mars Pathfinder project, and future missions should be able to learn from the Pathfinder lessons.

The project also had several technology objectives associated with successful demonstration of a low cost Mars atmospheric entry and landing system and deployment and operation of a microrover. The entry, descent, and landing system used a semi-passive approach incorporating an aeroshell, parachute, radar altimeter, solid retrorockets, and impact absorbing airbags. Instrumentation was included to provide aeroshell thermal performance data, atmospheric structure information, and trajectory reconstruction data. The microrover (named "Sojourner") is a partially autonomous, 10 kilogram vehicle that can traverse as far as 500 meters from the lander. The vehicle uses a six wheel rocker bogey suspension and a sophisticated set of on-board sensors to move around on the Martian surface. The microrover completed a set of detailed technology experiments designed to help validate the use of microrovers for Mars exploration. These experiments included autonomous navigation, solar array performance assessment, material adherence, and UHF link performance.

The Discovery program features low cost planetary missions with exciting, but focused scientific objectives. The primary science objective of Pathfinder was to characterize the surface geology and geomorphology of Mars. The combination of the rover and the Alpha-Proton-Xray Spectrometer provided a particularly powerful capability to address the chemical composition of Martian rocks and soil. In addition, the multi-spectral capabilities of the Imager for Mars Pathfinder allowed scientists to investigate rock mineralogy and surface soil properties near the lander. The IMP is a stereo, CCD camera with twenty-four color filters mounted on a one meter deployable mast. This camera was also used to assess the geomorphology of the landing area, and provide images for rover navigation and traverse planning. The lander instrumentation package also includes an Atmospheric Structure/Meteorology package used to obtain data on the structure of the Martian atmosphere along the entry and descent trajectory and to monitor meteorological conditions at the landing site. The final scientific objective is to investigate the orbital dynamics of Mars by studying movements in the inertial position of the landing site. These variations reveal information about the structure of the Martian core and mantle as well as better understanding of seasonal changes in the Martian atmosphere.

Launch, **Cruise, and Mars Entry, Descent, and Landing**

Mars Pathfinder was launched from the Cape Canaveral Air Station on December 4, 1996, on-board a McDonnell Douglas 7925 launch vehicle. Figure 1 shows a picture of the spacecraft in the launch configuration just before being encapsulated in the Delta shroud. The launch was nearly flawless, and the Delta third stage placed the spacecraft on a near nominal trajectory to Mars. The only concern was contamination of the attitude control sun sensor located on the cruise stage. The sensor continued to work well enough, however, that there was no long term effect on the mission. A number of activities were performed early in cruise, including initial spacecraft checkout, health checks of the science instruments and Sojourner microrover, and the first two Trajectory Correction Maneuvers. Most of the remainder of the seven month cruise was relatively quiescent except for periodic attitude turns, payload health checks and trajectory correction maneuvers. The flight team used this opportunity to perform extensive test and training for entry and surface operations. Several activities were performed just before arrival including uploading a new version of flight software, charging the lander battery, and performing the final trajectory correction maneuver.

The Entry, Descent, and Landing (EDL) phase of the mission started on June 30, 1997, when the EDL control software was initiated. Two timing updates were sent to the spacecraft to make slight corrections to the default cruise stage and parachute deploy times. A final Trajectory Correction Maneuver could have been performed just prior to entry, but was not required to meet the landing site targeting requirements. The landing site target was a 200 km by 100 km ellipse centered on Ares Vallis (19.3”N, 33.6°W). The actual spacecraft trajectory had a flight path angle of -14.06° and arrived within 23 km of the center of the ellipse. The first EDL activity performed by the spacecraft was to vent the heat rejection system used to cool the spacecraft during cruise. This occurred at approximately 8:30 am PDT on July 4, 1997. The 70 m antenna at the Deep Space Network station in Madrid, Spain was used to observe the spacecraft carrier signal during this critical approach phase.

The next major activity was cruise stage separation, which occurred at 9:30 am, or about 30 minutes prior to entry. Peak atmospheric deceleration occurred two minutes after entry, when the vehicle sustained a peak load of about 16 g’s. Parachute deployment occurred at an altitude of 9.4 km, 134 seconds before landing. Although the spacecraft carrier signal was not detected during peak deceleration and parachute deploy, it was reacquired at Madrid shortly thereafter. Heat shield release, lander bridle separation, and radar altimeter acquisition all occurred at the expected times (relative to parachute deploy). The radar altimeter acquired data starting at about 1.6 km from the surface and maintained lock through rocket ignition. The descent rate on the parachute was somewhat higher than expected, but well within the design envelope. The rockets were ignited about 98 m above the ground, and lander separation occurred at an altitude of 21 m. Landing occurred at 9:56:55 am PDT at a vertical impact speed of 14 m/s and a peak initial deceleration of 18.6 g’s. At least 15 subsequent bounces occurred before the lander came to rest on the base petal about 2 minutes later. The spacecraft carrier signal was not observed during the bounces, but was obtained again after the lander came to rest. The airbags were then retracted and the lander petals opened. The EDL phase ended officially at 11:34 am, when the petals were fully deployed and the lander moved on to the surface phase.

Surface Operations

Surface operations started in earnest at 2:09 p.m. PDT on July 4 (7:09 a.m. Local Solar Time on Sol 1) when first telemetry data was received on the ground. This data consisted of lander and rover engineering data, plus information summarizing the performance of the EDL system. At 3:20 p.m., commands were radiated to deploy the High Gain Antenna (HGA), perform sun search, point the HGA, acquire the first images using the IMP, and downlink them over the HGA. The first images included engineering pictures of the airbags and rover ramp deployment area, and the mission success image. The mission success image, shown in Figure 2, was a color view of the undeployed rover in front of background containing the Rock Garden, Twin Peaks and the Martian sky. The engineering images acquired during this first HGA downlink indicated that the airbags under the rover petal were not fully retracted and would impede deployment of the rover ramps. As a result, the flight team sent commands to raise the rover petal to 45° angle and further retract the airbags. More engineering images were then acquired which indicated that the rover ramps could be safely deployed. At 9:30 p.m., commands were sent to deploy both ramps and drive the rover into the standing position. The final downlink of the day indicated that the ramps had been successfully deployed (although the end of the front ramp did not touch the ground) and that the rover was ready to drive onto the Martian surface.

Sol 2 started at approximately 3:25 p.m. PDT on July 5, 1997, when the first HGA downlink occurred. This data indicated that the lander had experienced a flight computer reset during the night, but that otherwise the lander and rover had performed well during their first night on Mars. The combination of the reset and the low morning temperatures also cleared up some intermittent rover-lander communications problems which had occurred on Sol 1. Commands were sent to drive the rover down the real ramp at 8:10 p.m., and Sojourner rolled onto the Martian surface at 8:30 p.m. The IMP mast was deployed at the end of Sol 2 after several sets of backup images had been acquired. Sojourner moved a few feet farther away from the lander on Sol 3 to obtain an APXS measurement of Barnacle Bill. The rover then spent the next few sols attempting to acquire an APXS measurement of Yogi, which it successfully acquired on Sol 9. Figure 3 shows an image of Sojourner attempting to place the APXS against Yogi.

The official prime mission for the rover ended on Sol 8 when all of its' mission objectives had been met. Operations continued, however, as the rover traversed to a number of interesting targets, including Scooby Doo, Souffle, Mini-Matterhorn, and Mermaid. By Sol 38, the rover had circumnavigated the lander and was ready to enter the Rock Garden. Several additional APXS measurements have been made in the Rock Garden, including Wedge, Shark, Half Dome, Moe, and Stimpy. The rover is now about to exit the Rock Garden, drive back around the lander, acquire an APXS measurement of the ramp magnet, and start exploring the far field away from the lander. All future rover operations will be performed during the daylight, however, because the rover batteries were fully depleted on Sol 55.

The lander performed a wide array of science activities during the first 60 days of the mission, and has so far returned more than 1.8 Mbits of data. More than 13000 images have been returned, including two full panoramas. Figure 4 shows the Gallery pan, a 6:1 compressed, color, 360° panorama acquired on Sol 11. An uncompressed stereo panorama in nine colors is currently being obtained, and should be completed by Sol 100. Other specific imaging targets include the atmosphere, wind socks, cloud formations, stars, Phobos, Deimos, and the sun. Multi-spectral images of many of the nearby rocks and soil deposits have also been acquired. Atmospheric temperature, pressure, wind speed and direction measurements have also been obtained throughout the first 60 sols. Full **24** hour coverage was obtained for most of the first 30 days, but data collection is now limited to the daylight hours. The lander battery capacity degraded as expected during the first thirty days to the point that night time operations are now only performed every 1-2 weeks. Day time measurements are obtained at a high frequency, however, to provide additional data on short time period variations in the atmosphere. Finally, periodic radiometric tracking data has been acquired from the lander to support the orbital dynamics investigation. Additional tracking data will be acquired over the next few months to complete this long term effort.

Initial Science Results

Significant results have already been obtained from all of Pathfinder's science investigations. Details on these results will be available in the 30 day science report, but three are particularly important and worth discussing here. The most important of these is the discovery of more than one type of rock at the Pathfinder site. APXS measurements of Barnacle Bill, Yogi, and the other rocks show that there are at least two types of rocks. This is not unexpected (because the Pathfinder site in the outflow channel of a catastrophic flood that may have transported rocks from different geologic regions of the planet), but confirmation is still important. More interestingly, one of the rock types (Barnacle Bill is an example) appears to be relatively high in silicon. This result could be caused by weathering, but may also be caused by more differentiation during the early history of Mars. This is certainly a significant result, since it implies that Mars is not as primitive a body as expected, and may be more Earth like.

A second significant result from the mission was the observation of short time scale, large amplitude temperature variations in the lower atmosphere. Atmosphere temperature measurements taken at three heights on the ASI/MET mast indicate that temperature variations of 10 degrees or more occur over 3-4 second periods. These type of variations are likely cause by small scale turbulence and convective heating near the surface. Turbulent atmosphere phenomena are common on Mars, as evident by the dust devils that have been observed in the wind speed and pressure data.

The final key result is that the landing site physical characteristics are in very close agreement with pre-landing estimates. These estimates were obtained by using remote sensing data from the Viking missions, and making appropriate geological interpretations of the data. The landing site is clearly in the middle of a depositional plan created by catastrophic floods in the Ares and Tiu Vanes. The overall rock coverage agrees very closely with estimates made from Viking thermal inertia data. The overall surface roughness and the site elevation compare well with observations made from Earth based radar. This general agreement means that the interpretations of Martian geological, geophysical, and atmospheric processes obtained from studying remote sensing data are generally accurate. This is a powerful result which significant increases the usefulness of future orbital missions like Mars Global Surveyor.

Conclusions

The Mars Pathfinder Project has been an unqualified success, both in demonstrating new ways of doing business at NASA and completing a set of challenging mission objectives. This mission has started NASA's new Mars Exploration Program off on the right foot, and has already answered many perplexing questions about our nearest planetary neighbor. Future missions will inherit much from Pathfinder, both in terms of technology and as an example of "Faster, Better, Cheaper". This mission has excited the industry and the public, and clearly shows that space exploration is part of our collective destiny.

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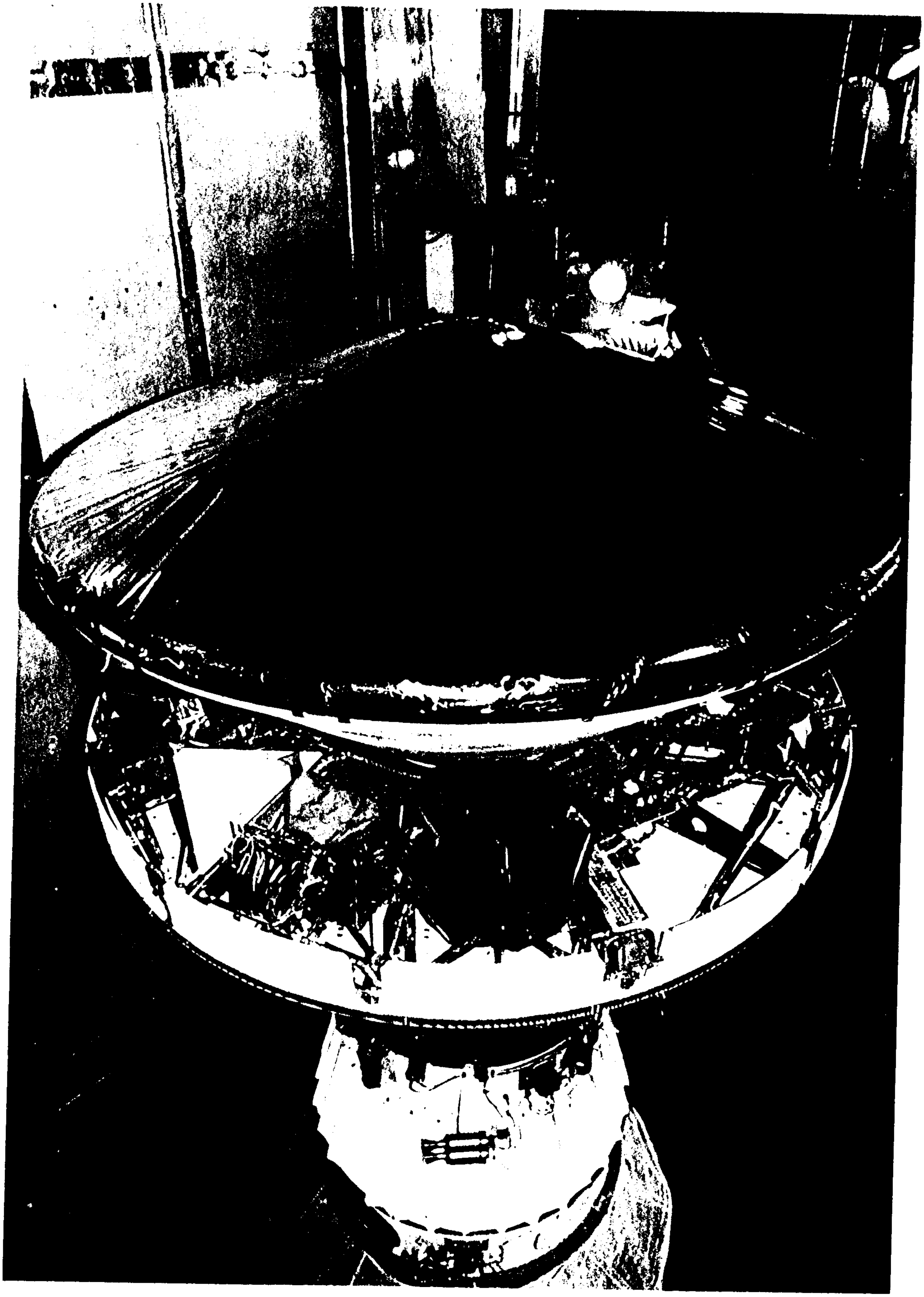

Figure 1 Mars Pathfinder Spacecraft in Flight Configuration

Figure 2 Mission Success Panorama

Figure3 Sojourner and Yogi

Figure 4 Gallery Panorama